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Radiation Protection: The NCRP Guidelines and Some Considerations for the Future

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The National Council on Radiation Protection and Measurements (NCRP) in the USA and the International Commission on Radiological Protection (ICRP), worldwide, were formed about 1928 and have since made recommendations on appropriate levels of protection from ionizing radiation for workers and for the public. These recommendations and much of the guidance provided by these organizations have usually been adopted by regulatory bodies around the world. In the case of the NCRP, the levels have fallen from 0.1 roentgen per day in 1934 to the current 5 rem per year (a factor of about 5). The present levels recommended by both the ICRP and the NCRP correspond to reasonable levels of risk where the risks of harm from ionizing radiation are compared with the hazards of other, commonly regarded as safe, industries.

Some considerations for the future in radiation protection include trends in exposure levels (generally downward for the average exposure to workers) and improvements in risk estimation; questions of lifetime limits, de minimis levels, and partial body exposures; plus problems of high LET radiations, acceptability of risk, synergisms, and risk systems for protection.

INTRODUCTION

Radiation Protection *standards* are established and enforced by regulatory agencies of the federal government in the USA and by the individual states. In the case of the federal government, a large number of agencies are involved in different aspects of radiation legislation, including the EPA, NRC, BRH, NIH, DOT, DOL, DOE, DOI, etc., and these agencies sometimes act in an uncoordinated way since the Federal Radiation Council no longer exists.

While the government clearly has the responsibility and the only authority to legislate on the exposure of workers, exposure of the public, and on the various radiation uses and users, it has most often in the past relied upon the advice and recommendations of scientific bodies who examine evidence relating to radiation effects and make recommendations concerning the appropriate levels as a result of these examinations. While the right of these bodies to make such recommendations has sometimes been challenged, we must assume that informed scientific input is an important starting point for any consideration of standard setting. I therefore intend to discuss the scientific basis for protection recommendations.

ICRP AND NCRP

The principal scientific bodies engaged in this work are the International Commis-

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sion on Radiological Protection (ICRP) worldwide, and the National Council on Radiation Protection and Measurements (NCRP) in the USA. Both started as a result of deep concern and much professional and public agitation in the 1920s over the effects of X radiation (in radiologists and patients) and of radium ingestion, which were just then becoming appreciated. Typically, not government but professional action was the tenor of those times and the First International Congress of Radiology in 1925 (London) initiated the establishment, in 1928, of two International Commissions, one on units and measurements (ICRU) and one on radiological protection (ICRP). These commissions have continued to meet and to report in their respective fields for the ensuing 50 years, ICRU on units (the roentgen, the rad and the rem, the Gray and the Sievert, and various other units come from there), and the ICRP on protection levels and guidance relating to them. At about the same time, the U.S. Advisory Committee on X-Ray and Radium Protection was formed (1929) and later became the National Council on Radiation Protection and Measurements chartered by the Congress of the United States in 1964.

About its early organization, Lauriston Taylor [1] says the following:

> Upon my return from the Second International Congress meetings in 1928, I immediately made contact with the officers of the several radiological societies in this country seeking their reactions as to the organization of some kind of central advisory group for radiation protection. These discussions took place at two of the larger societies and, with their support, I organized what was then known as the Advisory Committee on X-Ray and Radium Protection. While the records on this are not clear, it is believed that the original intention was that the Committee would be advisory to the U.S. member of the International Committee, namely, L.S. Taylor, and especially concerned with the development of a single U.S. opinion for international deliberations on the subject. However, the early success of the work of the Committee was such that the societies liked to feel that the Committee was advisory to them. Also, because the National Bureau of Standards was in the process of organizing a major program in radiation protection and measurements, it liked to feel that the Committee was advisory to it. The picture can probably be best described by saying that the Committee liked to feel that it was willing to be advisory to anyone who wished to be advised and that is the way the situation has been.
>
> One thing emphasized from the very beginning was that the Committee was not a government committee and was not supposed to be so regarded. It was a Committee to represent expert opinion.

Thus did the NCRP originate!

The NCRP and the ICRP have, over the fifty-year period, provided recommendations on protection levels for workers and more recently for the public and provided also much guidance and informational material. A summary of the principal protection levels recommended by these bodies over the fifty-year period is shown in Table 1.

The first "official" recommendation for a tolerance dose came from the NCRP, in March of 1934, which recommended a level of 0.1 roentgen per day. It was based upon the absence of observable harm, the most immediate observable harm being, at that time, the production of skin erythema. Indeed, the "erythema dose" was widely used as the base for dosimetry until physical measurement and the definition

TABLE 1
Protection Recommendations 1928-1980

	NCRP		ICRP	
Year	Limit	Annual Equivalent	Limit	Annual Equivalent
1934	0.1 R/day	~30 R	0.2 R/day	~60 R
1949-54	0.3 rem/week	15 rem		
1950-54			0.3 rem/week	15 rem
1957	$5(N - 18)$ rem 10 rem/30 year	5 rem (15 rem maximum) Public 1/3 rem average		
1958			$5(N - 18)$ rem	5 rem (15 rem maximum) Public 5 rem/30 year 170 mrem average
1971	$5(N - 18)$ rem	5 rem (15 rem maximum) Public 500 mrem, individual 170 mrem, average		
1977			5 rem/year	5 rem Public 500 mrem (maximum) 50 mrem average

Occupational levels except where noted.

of the roentgen by ICRU in 1928 provided a sounder base for dose measurement. The erythema dose was estimated at about 550 R and the tolerance dose was based first, on one-tenth of an erythema dose per year and later one one-hundredth of an erythema dose per month. ICRP, using the same information but somewhat less conservative rounding figures, set a tolerance dose of 0.2 roentgen/day in July 1934.

These levels prevailed for some 15 years. Then as a result mainly of the appreciation after World War II that radiation uses were likely to expand greatly, and as more and more people became involved, it was considered wise to be more cautious. NCRP, first in 1949 and later in 1954 [2], and ICRP, in about the same time frame [3], both adopted 0.3 rem/week or 15 rem/year.

However, this was not maintained for long. About this time concern over genetic effects became widely evident and reports of the Medical Research Council in England and the National Academy of Sciences in the USA in 1956 resulted in NCRP and ICRP adopting a lower effective annual level of 5 rem/year. This was not because of any observed harm, but rather because of the general public concern. To this day, no harm has actually been observed in people exposed at former protection levels although some day perhaps it will be. Both NCRP and ICRP used, at that time, a dose accumulation formula of $5(N - 18)$ rem where N is the age in years. This formula was designed to provide flexibility in applying standards in practice. The ICRP dropped the accumulation formula in 1977 [4]; NCRP still has it, in Report 39 of 1971 [5].

Obviously, the recommendations of both NCRP and ICRP have become more conservative with time (by about a factor of five to ten) as knowledge about radiation effects has improved and the desire to avoid them has become more intense.

There has, however, been relatively little change in the levels since 1958, 5 rem/year being a substantially steady maximum level for occupational workers. Experience with this level as a maximum has shown that the average exposure of workers is only 1/3 rem/year [6].

Let us now take a somewhat closer look at the NCRP: its organization and some facts about it. It was founded in 1929 as a National Advisory Committee and became the National Council on Radiation Protection and Measurements in 1964 with a charter from the Congress of the United States. The Council has 75 members who serve six-year terms and are drawn from a wide range of different scientific talents and from all parts of the USA. It is governed by an eleven-person Board, chaired by a president. It has more than sixty active scientific committees and task groups engaged in studies on a wide range of topics in radiation protection. These include, broadly, basic radiation protection criteria and recommendations of which Report 39 [5] is an example; assessment of exposure to the population—Report 45, Natural Background on the USA [7] is an example; guidance in selected areas in which Report 68, Radiation Protection in Pediatric Radiology [8] offers an example; and information in which Report 44 on Krypton-85 and Its Properties [9] and [10] is an example. The NCRP also addresses effects and protection recommendations in certain non-ionizing radiation fields such as microwaves, ultrasound, and magnetic fields. Its first report in this area, Report 67 on Radiofrequency Electromagnetic Fields [11], was published in 1981. Typically, an NCRP committee produces a draft report on a given subject area which is reviewed by the entire Council and is ultimately a product of the entire Council. Reports are produced at the rate of three to six per year and copies are sold at nominal cost and receive wide distribution. The NCRP also holds an annual scientific meeting, and reports on the progress of scientific committees are available to all who attend. The NCRP seeks to serve and inform the public on all matters of radiation protection.

NCRP RECOMMENDATIONS AND RISK QUANTIFICATION

The current NCRP recommendations were produced in 1971 [5] and were based mainly on experience, notably the absence of observed harm, even though some estimates of risk were given. Reports by two other bodies, the United Nations Committee on the Effects of Atomic Radiation (UNSCEAR) [12] and the Committee on the Effects of Ionizing Radiation of the U.S. National Academy of Sciences (BEIR) [13] in the following year, 1972, contained detailed estimates of risk. Nevertheless, in a further report on radiation protection philosophy (Report 43 in 1975) [14], the NCRP saw little reason to change its approach to protection recommendations. Some features of the UNSCEAR and BEIR Committees follow.

The UNSCEAR is a 20-member (nation) Committee reporting to the General Assembly of the United Nations in which the USA and 19 other countries participate. It examines worldwide the levels of radiation occurring from all sources and the latest information on biological effects. It has produced a wide range of reports over the years since 1955, with especially significant reports in 1972 and 1977.

The National Academy of Sciences in the USA has appointed committees to study aspects of ionizing radiation. Notable among these were the BEAR Committee of 1956 and the BEIR (I) Committee of 1972 and the BEIR (III) Committee of 1980.

The current UNSCEAR risk estimates are contained in their report of 1977 [15] and formed important (parallel) input to the ICRP recommendations of Report 26, in 1977 [4]. The most recent revision of the BEIR Committee's work appeared in 1980 [6] with risk estimates generally in good agreement with UNSCEAR in 1977 [15].

ICRP RECOMMENDATIONS

The ICRP Report 26, in 1977 [4], containing the current recommendations of ICRP, is being widely publicized and explained. Detailed discussions of its uses have been held around the world, and by bodies such as the International Atomic Energy Agency who assist in the implementation of protection recommendations. The principal features of the report are that it discusses the risks of ionizing radiation in detail and estimates a total stochastic risk of $10^{-2}Sv^{-1}$ and a total genetic risk, $4 \times 10^{-3}Sv^{-1}$. It reaffirms occupational exposure levels: adults irradiated uniformly whole body should not exceed 50 mSv/year (5 rem/year), i.e., somatic risk has a maximum value of 5×10^{-4}/year.

It permits higher exposure of individual organs when the body is irradiated non-uniformly by the application of the following weighting factors:

Tissue	Weighting Factor
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

It suggests that exposure of individual members of the public be limited to 5 mSv, in which case the *average* exposure should not exceed 0.5 mSv. It promotes the principle of optimization of protection procedures to keep exposures well below these limits. For internal emitters, ICRP has produced its Report 30 and supplements, on Annual Limits of Intake for Internal Emitters [16].

Let us return for the moment to the question of the maximum permissible level and its significance in terms of risk. ICRP did not define an acceptable level of risk. Rather they have adopted the view that the maximum level (5 rem/year) is a level never to be exceeded and rarely approached, which together with ALARA (As Low As Reasonably Achievable), results in average exposures to workers of only about one-tenth the maximum, or 0.5 rem/year. Choosing a lifetime risk level of 10^{-4} per rem, the average exposure corresponds to a lifetime risk level of 5×10^{-5}/year which is found (ICRP 27) [17] by comparison with the loss of lifetime due to accident rates, etc., to be comparable with very safe industries. By implication, this level of risk or perhaps a somewhat higher risk, 10^{-4}/year, is taken to be acceptable for occupational exposure.

Furthermore, as noted above, current limits, good practices, etc., result in the public getting no more than about 50 mrem per year above background (exclusive of medical) which is regarded (a risk of 5×10^{-6}/year) as a reasonable level of risk compared to many other hazards normally encountered by the public.

FUTURE PROTECTION CONSIDERATIONS

The system developed by ICRP in Report 26 is being implemented in many parts of the world. We must, of course, continue to assess our own protection situation in the United States, incorporate new information as it becomes available, and determine the effectiveness of protection levels and procedures in keeping exposures to workers and to the public at a reasonable level consistent with ALARA.

In this connection, I want to discuss three areas: (*i*) one about risk levels themselves, (*ii*) one about exposure levels, and (*iii*) one about recommended levels and areas of concern with respect to them in the future.

Risk Levels

Our current best estimate of the risk from low LET radiation at low dose levels and dose rates is that given by UNSCEAR 1977 [15] as 10^{-4}/rad (Table 2).

These estimates are, however, fraught with many uncertainties, of which I shall mention some [18,19]:

1. absolute value of risk for leukemia, 2×10^{-5} rad^{-1}
2. total cancer mortality $\simeq 5 \times$ leukemia $= 10^{-4}$ rad^{-1}
3. age dependence
4. sex dependence
5. fatal vs. non-fatal cancers
6. absolute risk vs. relative risk models
7. absorbed dose to specific organs (kerma; absorbed dose)
8. allowance for dose/dose rate
9. extrapolation from high doses (> 100 rads) to low doses
10. X and gamma rays treated alike

TABLE 2
Somatic Mortality Risk at Low Doses (UNSCEAR – 1977)

Cancer	Risk Estimate (Range)	"Best" Value
Leukemia	$15\text{–}50 \times 10^{-6}$ rad^{-1}	2×10^{-5} rad^{-1}
Thyroid	$5\text{–}15 \times 10^{-6}$ rad^{-1}	1×10^{-5} rad^{-1}
Breast	$10\text{–}60 \times 10^{-6}$ rad^{-1}	5×10^{-5} rad^{-1}
Lung	$20\text{–}50 \times 10^{-6}$ rad^{-1}	2.5×10^{-5} rad^{-1}
Bone	$2\text{–}5 \times 10^{-6}$ rad^{-1}	0.5×10^{-5} rad^{-1}
Brain, Salivary Glands, Stomach, Liver, Large Intestine	$10\text{–}15 \times 10^{-6}$ rad^{-1}	$\sim 1 \times 10^{-5}$ rad^{-1}
Oesophagus, Small Intestine, Pancreas, Rectum, Bladder, Ovary, Lymphoid Tissue, Cranial Sinuses	$2\text{–}5 \times 10^{-6}$ rad^{-1}	0.5×10^{-6} rad^{-1}
Total Cancer Risk	Female	1.5×10^{-4} rad^{-1}
	Male	1.0×10^{-4} rad^{-1}
	Average	1.25×10^{-4} rad^{-1}
	Adult Ages Only	1.0×10^{-4} rad^{-1}

I shall not attempt to discuss all these points, but I shall mention one or two by way of example. The age composition of the population exposed is important because of the dependence of cancer incidence upon age. We know this dependence in some instances, such as leukemia, moderately well (Fig. 1). It will be different in other cases such as thyroid, breast, and lung.

The absorbed dose to the organs concerned, requires, in the case of the Japanese exposures at Hiroshima and Nagasaki, a knowledge of the kerma as a function of distance from the explosion plus a knowledge of the absorbed dose to individual organs as a result of exposure of a person to the kerma at a point. The kerma is determined from weapon output spectra and yield, and transport equations for neutrons and gammas through a humid atmosphere. Recently, revisions have been proposed in the estimates of kerma which may force us to modify our interpretations of some of the data from the atomic bomb survivors [20].

A useful way to express some additional points is by a comparison of the UNSCEAR data and the recent BEIR Report of 1980 [6] (Table 3). The BEIR Report estimates risks for both absolute and relative models and gives information on the differences for different extrapolation (dose effect) models (Fig. 2).

Some scientists believe that, especially for gamma rays, we don't know the actual risk within a factor of 100. Some say the risks are much lower, others that they should be much higher than in Table 2. However, many scientists support the view that our current risk estimates are probably within a factor of 5 (multiple or one-fifth) and possibly within a factor of 3 (or one-third) of the UNSCEAR estimates for low doses.

EXPOSURE LEVELS

The ICRP estimates an average of 0.6 rem/year for radiation workers (U.K. data) [17] in determining that the risks associated (with this dose) were comparable or better than the risks in "safe" industries. United States data is surveyed by numerous

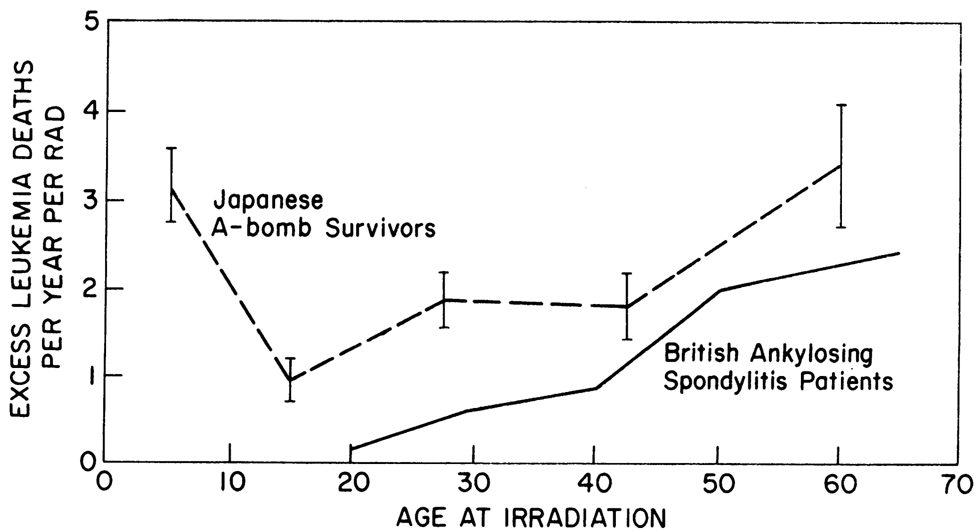

FIG. 1. Excess deaths per million persons per year per rad to bone marrow, atomic-bomb survivors and ankylosing-spondylitis patients, by age at irradiation. Vertical bars indicate 90 percent confidence intervals.

TABLE 3
Comparison of Cancer Deaths Potentially Induced UNSCEAR (1977) and BEIR (1980)

	Number of Cancer Deaths per Million			
	USA	BEIR III* 1980		UNSCEAR 1977
Single Dose		Abs.	Rel.	
10 rad	163,800	766	2255	1000
Increase %		0.4%	1.4%	
Continuous Dose				
1 rad/year lifetime	167,300	4751	12920	7000
Increase %		2.8%	7.7%	

*Note: This is for LQ model
L-L model × (2–3)
Q-L model × ~1/10th or less

groups including NRC, EPA, and NCRP's Committee 45. Some data taken from BEIR 1980 [6] are shown in Table 4.

The average of all occupational workers is approximately 0.3 rem (300 mrem) or less. The trends described in the BEIR Report show the number of workers to be increasing but the average exposures to be declining.

Population exposures as determined by BEIR 1980 [6] are given in Table 5. The

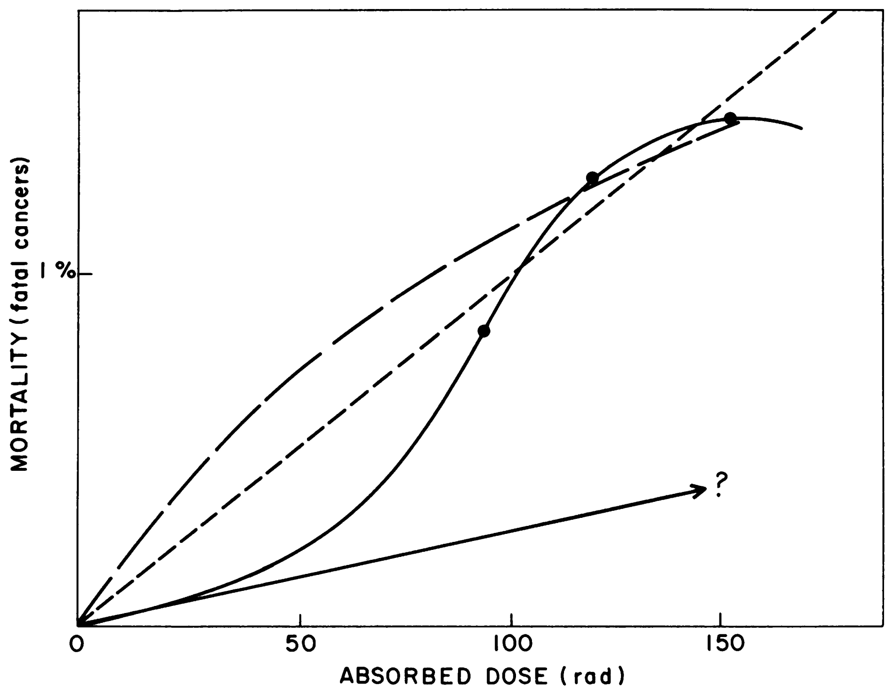

FIG. 2. Mortality from cancer against absorbed dose to the relevant organ. Data points obtained at higher doses must be extrapolated downward in order to describe the dose effect relationship at lower doses. Different methods of extrapolation linear, supralinear, and below linear are shown.

TABLE 4
Occupational Exposures

	Number of People	Average Annual Exposure
Medical		
Diag. X rays—medical	195,000	300-350 mrem
Diag. X rays—dental	170,000	50-125 mrem
Radiopharmaceuticals	100,000	260-350 mrem
Nuclear Industry		
Power plants	67,000	400 mrem
Industrial radiography	11,250	320 mrem
Fuel processing	11,250	160 mrem
By-product material handling	3,500	350 mrem
DOE contractors	88,500	250 mrem
Naval nuclear propulsion	36,000	220 mrem
Research Activities		
Electron Microscopes, etc.	4,400	50-200 mrem
Airline Crews	40,000	160 mrem

Source: BEIR 1980

estimates differ little from similar estimates made five years ago and, consequently, the average exposure of the population would not seem to be increasing.

Recommended Levels

The NCRP, having last produced recommendations in 1971 and these being based not on risk estimates or on acceptable levels of risk but rather on experience and practice, is reconsidering its position with respect to an adequate radiation protection system. While it is not possible to prejudge what the NCRP will eventually decide to do, some areas of concern are the following:

1. *Lifetime Risk and Exposure Limit*—The $5(N - 18)$ formula was introduced by NCRP many years ago primarily for flexibility. This formula and also ICRP's 5 rem/year do technically permit a person to be exposed during 47 years of working life to $47 \times 5 = 235$ rem, although ALARA and optimization would usually prevent this. The increased cancer risk associated with a nominal 250 rem might be of the order of 2.5 percent, i.e., more than a 10 percent increase in the current probability of dying of cancer, which is about 16 percent. This unlikely exposure situation could be avoided entirely by lowering the annual limit, which many think is adequate because it leads to reasonable average occupational exposures. Alternatively,

TABLE 5
Annual Population Exposure

Natural background	84 mrem (65-125 mrem)
Medical exposure	90 mrem
Fallout	4 mrem
Nuclear power	<1 mrem
Research activities	<1 mrem
Consumer products (Building materials)	3-4 mrem
Airline travel	0.5 mrem
Airline crews	160 mrem

Source: BEIR 1980

a lifetime limit of 50 or 100 rem could be introduced, if exposure records indicate that exposures in excess of the chosen limit are at all likely. A lifetime limit may have some disadvantages however, including "burning out" of workers, and so on, unless some administrative control is applied.

Another concern with respect to limits is the possibility of exposure of groups of people especially sensitive to radiation, such as individuals with ataxia telangectasia [15]. Presumably such individuals would not be suitable as radiation workers, but in the future other sensitive groups might be identified for which special consideration may need to be given.

2. *De Minimis or "Insignificance" Levels*—The "de minimis" concept, derived from "de minimis non curat lex," "the law does not concern itself with trifles," would define a level or source that could be treated as too small to be of concern. This could be very useful in many contexts, e.g., the classification of low-level waste. Unfortunately, it is difficult to get agreement on such a concept because its meaning is perceived differently by different viewers. For example, a truly de minimis quantity is one which is so small that no number of such quantities could ever be significant in its effects. Strictly, only zero would do for an infinite number of such quantities or sources. A reasonable compromise is to define two quantities: one a de minimis level or source could be envisaged sufficiently small that no reasonable number of sources could constitute a hazard—for example, 0.1 mrem; the other, an "insignificant level" at which the effects would not be considered important compared with other hazards in everyday life; for example, 10 mrem, which is about 10 percent of natural background and also about the standard deviation of the variation in background, might be such a number.

3. *Partial Body Irradiation*—The ICRP system attempts to equate the risks from partial body irradiation to those of whole body using organ weighting factors. While the system developed is comprehensive and consistent, future information on risks may modify our notions of the relative importance of the different organs. Thus, some modifications of weighting factors or a different approach may be required here to have a balancing of risks that is more satisfying in partial body exposure circumstances.

4. *High LET Radiations*—The dose effect relationships for high LET radiations, their shape, whether fractionated doses increase the effect, and the actual levels of RBE, and, therefore, Q to be assigned, have all come into question.

Concerning the shape, some neutron dose effect curves appear to be essentially linear, as in the example shown in Fig. 3, taken from the work of Rossi and Mays [21] for the incidence of fatal leukemia in the Japanese at Hiroshima exposed to neutrons after subtraction of the gamma ray component. Note that for a 20-year period at risk, the risk rate given here, 28×10^{-6}/year/rad, yields a total risk of approximately 60×10^{-5} rad^{-1} for leukemia. A similar high rate is found for the lung, but not for such others as breast and thyroid. The high risk rates are higher than is compatible with current values of Q, viz. 10, for these neutrons. Interpretations may change if the dosimetry at Hiroshima and Nagasaki is substantially modified.

Recent evidence suggests that dose effect relationships substantially different from linear may apply in some high LET circumstances. For example, some data on lifeshortening (Fig. 4) from the JANUS reactor studies at Argonne National Laboratory [22] show the gamma ray response virtually linear and the neutron response quite curvilinear, and the RBE over much of the range is substantially more than 20.

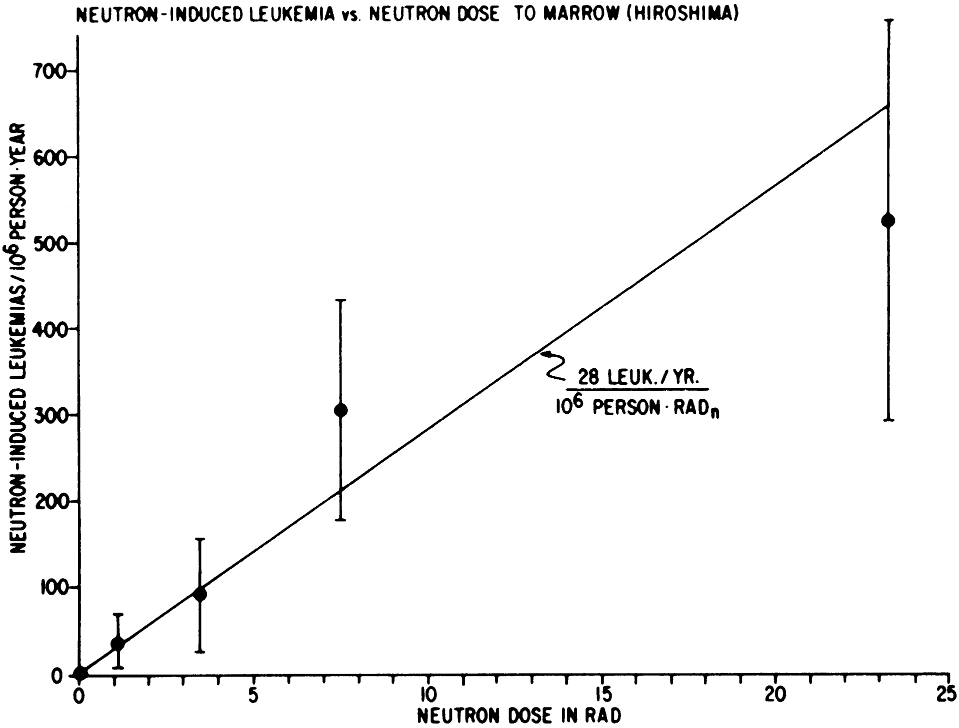

FIG. 3. Neutron-induced leukemia vs. neutron dose from data at Hiroshima and Nagasaki. The incidence rate appears to rise linearly with neutron dose at the indicated slope. There is no evidence for a threshold, even at the lowest neutron dose of about 1 rad. *Source:* [21].

In a significant number of circumstances, fractionation leads to higher tumor incidence (or lifeshortening) than for single dose, as would be expected from a curvilinear dose response curve. An example of preliminary data from JANUS reactor experiments is shown in Fig. 5.

These considerations certainly give one cause to wonder about present risk rates for high LET radiation. These collective concerns were the basis of the recent precautionary statement from NCRP about neutrons [23].

5. *Acceptable Risk*—Acceptable or reasonable levels of risk must either be chosen or implied. ICRP did not define an acceptable level of risk, but, as noted earlier, recognized that their dose limit system led to average exposures for workers which correspond to risks commonly encountered in safe industries. By implication, a level of risk of about 10^{-4}/year was taken to be acceptable for occupational exposure. Also, ICRP points out that current limits, good practices, etc., will result in the public getting no more than about 50 mrem per year above background (exclusive of medical) and this is regarded (risk 5×10^{-6}/year) as an acceptable level of risk compared with many other hazards normally encountered by the *public*. Clearly, acceptability will have to be generalized for all kinds of pollutant exposure circumstances as time goes on.

6. *Comparative Risk*—Clearly, the basis for comparison of risk between radiation and other sources needs to be better developed. Present comparisons with industrial accident rates must be examined and ratios for higher and lower risk groups, as well as averages, determined. Comparative risk techniques must be more

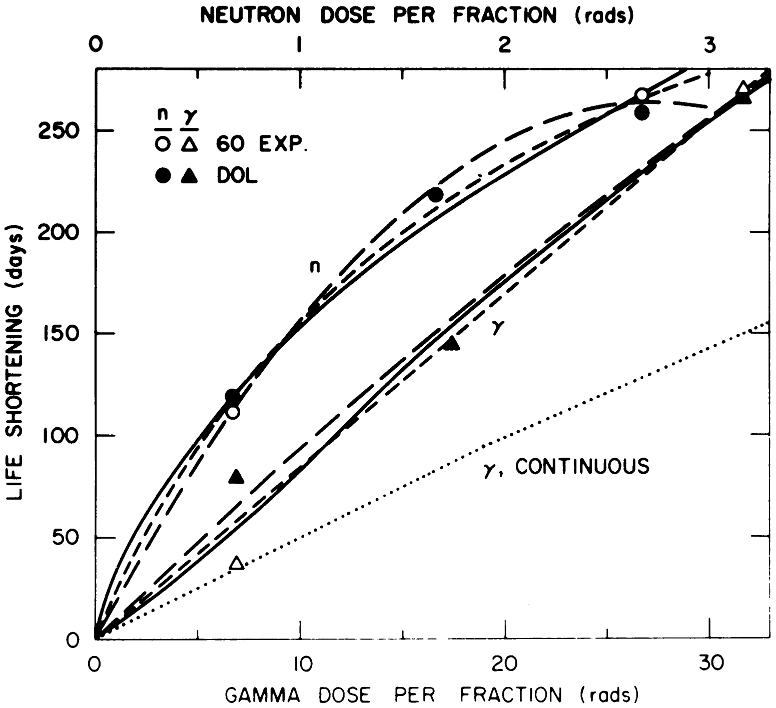

FIG. 4. Lifeshortening in the mouse vs. dose (upper scale for neutrons; lower scale for gamma rays, both in rads). Open symbols: 60 fractions. Closed symbols: duration of life exposure, given once weekly. The different curves through the points represent the fitting of different models to the data.

sophisticated as more data from other carcinogenic sources, non-nuclear pollutants, chemicals, and the like become available and dose effect curves are established.

7. *Synergisms*—An important part of any future protection system once it is broadly based on risk from all sources will be questions of additivity, multiplicity, or synergistic effects between pollutants. These questions are probably already plaguing and confusing some of our existing studies, and their elucidation will ultimately become of major importance in defining an overall hazard or risk level *from all pollutants.*

8. *Risk Systems*—As our knowledge of other pollutant hazards improve, comparative risk becomes better understood, and synergisms, and so on are accounted for, we will need to be able to express our limits in the same units in order to add them. These will clearly no longer be physical or chemical doses but will have to be estimates of risk or detriment. They will result in the acceptance ultimately of so much risk or so much detriment for a given circumstance.

Whether it is appropriate or desirable to start moving now in the direction of a pure risk system which involves (a) a physical measure of the exposure in physical units, (b) a dose effect curve, and (c) an estimate of the exposure in risk or probability units, able to be added to those of other exposures, other radiations, or other pollutants altogether, remains to be discussed.

There clearly are difficulties in doing so too early, and many will feel uncomfortable unless physical units continue to be used to describe exposures even though they

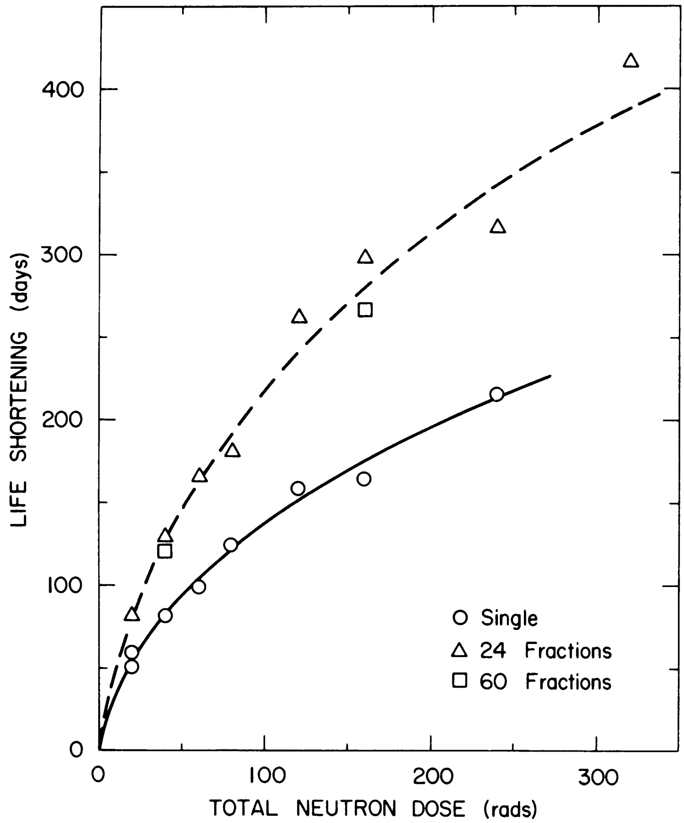

FIG. 5. Lifeshortening in the mouse vs. dose for single doses or multiple fractions for the same total dose.

are part of the record. A preliminary version of such a system has been published by Bond [24].

9. *Increase of Safety with Time*—Inevitably, as time goes on, society will demand greater and greater safety from risk-producing operations. The overall accident rates from all sources have declined steadily by a factor of three in the USA in the 50 years since 1928 (NSC data) [25]. They will continue to decline and thus present a moving target for radiation protection to compare with. We must remember that in a continuously developing society, attitudes change and a system deemed to be satisfactory at one time may only be temporary.

I have presented these thoughts with a view to the future. I believe the protection systems so far developed by NCRP (and ICRP) have been very effective over the years and the current systems will no doubt be used for some time to come.

However, there are very clearly uncertainties in our knowledge and some problems we can hope will be resolved with further research. Some of these problems I have tried to identify. There will be others not on this list that should also be addressed.

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